# 5G systems: The mmMAGIC project perspective on Use cases and Challenges between 6-100 GHz

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## Abstract

mmMAGIC (Millimetre-Wave Based Mobile Radio Access Network for Fifth Generation Integrated Communications) is an EU funded 5G-PPP project, whose overall objective is to design and pre-develop a mobile radio access technology (RAT) operating in the 6-100 GHz range, capable of impacting standards and other relevant fora. The focus of the project is on extreme Mobile Broadband, which is expected to drive the 5G requirements for massive increase in capacity and data-rates. This paper elaborates on some 5G key research areas such as: identification of the most compelling use-cases and Key Performance Indicators (KPIs) for future 5G systems, advantages and challenges of millimeter-wave (mmWave) technologies, channel measurements and channel modeling, network architecture; and the design of a new mobile radio interface including multi-node and multi-antenna transceiver architecture.

**Index Terms:** 5G system, mmWaves, use cases, channel modeling, RAT, 5G architecture.

## 1. Introduction

Over the past few years, the number of mobile devices per user has significantly increased: mobile phones, tablets, etc. In parallel, the capabilities of these equipment have also been improved in order to process more and more data: video with gradually increasing resolutions (Single Definition, High Definition, 4K), cloud applications, etc. Estimations of the growth for the overall mobile data traffic have been conducted and forecast an increase of at least 6500 PetaBytes/month by 2017— a 7-fold increase over 2013 [1]. Mobile communication systems should evolve to satisfy this tremendous increase in capacity by 2020 and beyond.

The requirements for the fifth generation of mobile communications (5G) are multi-fold, and future extreme Mobile Broadband (xMBB) systems should not only meet the significant requirements for capacity increase, but also address the needs for higher user data rates (up to 10 Gbps for services such as 3D immersive user experience and telepresence on mobile devices). Another key requirement for 5G is reduced latencies. Some services, such as interactive applications and ultra-responsive mobile cloud-services, will demand end-to-end latencies as low as 1 ms. And the user should benefit from an improved and consistent Quality of Experience (QoE), wherever he/she goes and in all situations.

The Millimetre-Wave Based Mobile Radio Access Network for Fifth Generation Integrated Communications (mmMAGIC) project [2][3] has the mission to design and develop a concept for a mobile radio access technology (RAT) operating in mmWave bands, which is expected to be an integral part of the 5G multi-RAT ecosystem. mmMAGIC will focus on xMBB use, expected to drive the 5G requirements for massive increase in capacity and data-rates.

In this paper, mmMAGIC presents a selection of use cases that will be key representatives of the project focus areas, with the objective to illustrate ultra-high deployment and capacity. Spectrum suitability and main challenges in the pre-development of such new mobile RAT are also discussed. This paper is organized as follows: Section II provides a brief overview of existing studies on use cases, Section III describes mmMAGIC use cases, Section IV presents the main technical challenges to be tackled in the mmMAGIC project, and finally section V summarized the conclusions.

## 2. Selection of use cases

Relevant use cases for mmMAGIC were identified through a careful survey of multiple consortia and projects. The following were considered as reference due to their focus on 5G topics:

- The Next Generation Mobile Networks (NGMN) Alliance: White Paper [4] where 8 families of use cases and respective KPIs were developed to support the deployment of ultra-dense networks, highlighting the need for spectrum above 6 GHz;
- The Mobile and wireless communications Enablers for the Twenty-twenty Information Society (METIS) project: deliverables [5][6] where challenges, KPIs, scenarios and concrete test cases were proposed;
- The Millimetre-Wave Evolution for Backhaul and Access (MiWEBA) project: deliverable [7] backhaul/fronthaul scenarios plus access sub-scenarios;
- The Beyond 2020 heterogeneous wireless network with Millimetre-Wave Small cell access and backhauling (MiWaveS) project: use cases in the millimetre-wave spectrum [8];
- The IEEE 802.11ad and ay standardization Task Groups: use cases for very high throughputs in mmWaves bands.

Regulatory groups such as ITU-R Working Group WP5D, national US (FCC) and UK (Ofcom) regulatory bodies were taken into consideration for their work on some preliminary identification of frequency ranges in bands above 6 GHz [9] [10].

## 3. mmMAGIC use cases

In this section the eight key use cases identified by mmMAGIC are described. In [11] the mmMAGIC use cases at that time has been described and submitted to NGMN. Figure 1 shows the summary of all use cases, and how each use case heavily depends on one of the KPIs.

### A. Media on demand

This use case captures the needs of end users in a dense area wanting to watch videos (i.e., favorite movies) at their own preferred time. The same use case is described in [6]. The movie is typically transferred from a server to the user terminal as the movie is watched. Here, the challenge is represented by the connection density, which is estimated to rise up to 4000 users/km²; when most of the users in the same area want to access the media content at the same time. An outdoor to indoor propagation environment has to be considered, since Media on Demand is an indoor service provided with outdoor solutions.

### B. Cloud services

The main features of the 5G scenario "Cloud Services" according to [4][5][12] are: enhanced customization for individual users equipped with future mobile devices with higher display quality, fast response time to support interactive applications (e.g. video conferencing and gaming [13]), and ubiquitous support. However, this use case is focused on outdoor and larger indoor areas. The main challenge is represented by the traffic density coupled with the mobility (up to 750 Gbps/km² and up to 100 km/h) when, for example: self-driving cars are envisioned.

### C. Dense urban society with distributed crowds

In urban dense areas, slowly moving end users expect to have high capacity seamless connections to wireless services almost anywhere. User density and demands are variable (e.g., a massive crowd concentrated for a limited time in small areas, for public or sport events); and the kind of traffic is diversified (i.e., information about athletes, high definition (HD) videos, post on social networks etc). Indoor (e.g., malls or events hall), outdoor (e.g., stadiums) and outdoor/indoor propagation environments (to ensure uniform connectivity and capacity) have to be considered. The challenge here is the presence of massive crowds, when connection and traffic density are stressed up to a critical level of 150000 users/km² and 7500 Gbps/km² respectively. Considering the real time sharing of multimedia contents, the low latency – below 10 ms, coupled with the huge number of users, becomes also a very stringent KPI.

### D. Smart offices

Typically this use case covers indoor communications in homes and apartments as well as office buildings involving a high density of devices. The traffic pattern in smart office use cases can however differ greatly. Smart-office applications may either generate localized traffic that can be routed in the first access node, or via a few local hops, while use-cases such as video sharing generate traffic, which needs to be routed through the core network. Localized traffic could even be supported by Device-2-Device (D2D) communication. With respect to the propagation environment, indoor and outdoor to indoor (limited at cmWave and mmWave frequencies) have to be considered. The main challenges are represented by the user data rate coupled with the traffic density that is estimated to reach 1 Gbps and 15000 Gbps/km² respectively.

### E. Immersive early 5G experience in targeted coverage

5G mobile deployments will be initially required to provide targeted coverage for the early adopters. This is most likely to be in dense urban traffic hot-spots, with mmWave small cells. The early adopters would particularly want to benefit from the immersive multimedia experience provided by 5G

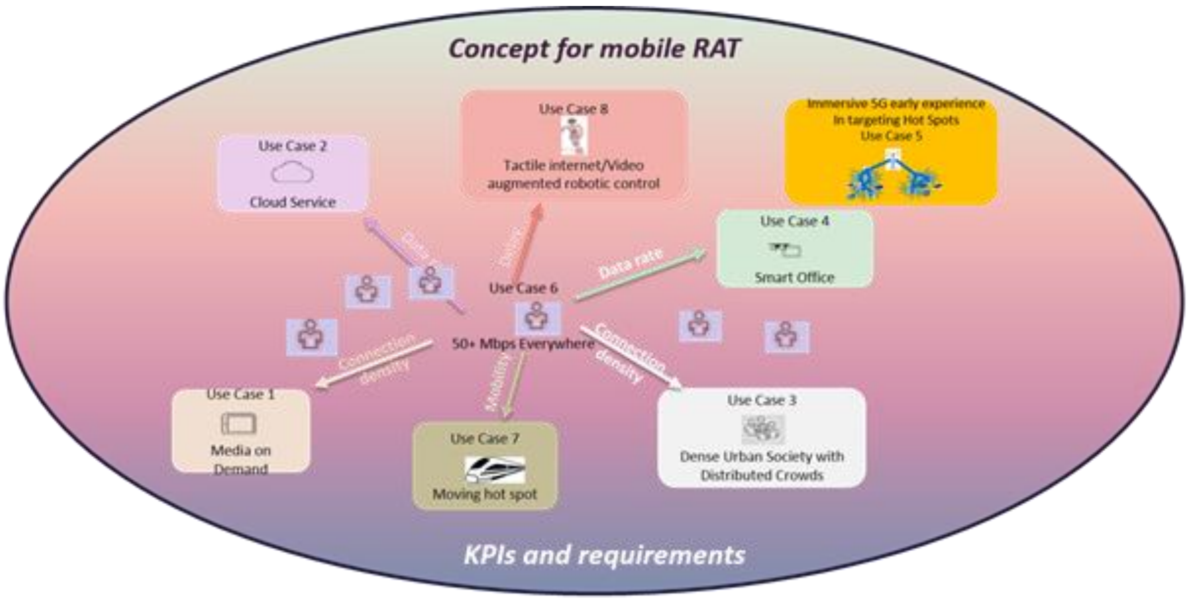


**Figure 1. Illustration of mmMagic use cases**

services, including 4k/8k ultra high definition (UHD) video, virtual reality and real time mobile gaming experiences. These 5G experiences should come with a palpable improvement from the QoE the users would get from the (then) legacy 4G services. Deployments such as Outdoor to Indoor, and Indoor to Indoor have to be considered. The dense deployment of small cells and the limited mobility of users studied under this use case will create opportunities for multiuser; distributed multiple input multiple output (MIMO) antenna solutions. It can also bring in complex interference management issues. Coordinated multipoint (CoMP) or beyond CoMP-type dynamic multi-cell coordination can be created to optimize different KPIs. The presence of underlay legacy cells operating in legacy RATs can bring more stability to the CoMP sets; but can also create challenges in accommodating Multi-RAT solutions.

## F. 50+ Mbps everywhere

A consistent user experience is expected from 5G systems, which translates into the provision of a uniform high data rate, or what is termed in ibid: "The edgeless RAN". While the projected edge data rates vary from 50Mbps [4] to 1Gbps [14], there is consensus [15] that this requirement (delivering high rates even at cell edge) will form an integral part of 5G.

NGMN, when defining this use case [4], indicates that the mobile and connected society will need broadband access to be available everywhere. Therefore, 50 Mbps should be understood as the minimum user data rate and not a single user's theoretical peak rate. Furthermore, it is emphasized that this user data rate has to be delivered consistently across the coverage area (i.e. even at cell edge). We argue that the comprehensive answer to this issue lies in the availability of new spectrum together with the deployment of ultra-dense networks.

## G. Moving Hot Spots

In the future there will be a growing demand for the broadband mobile communication with different requirements. We can distinguish different use cases depending on the required degree of mobility: moving crowds (e.g., moving mass events), moving vehicles (cars, buses, etc.), high speed trains and even aircrafts. We focus on high speed trains and moving vehicles (cars, buses). From the services perspective we focus on access to mobile broadband networks for in-vehicle entertainment and Internet services. The advanced navigation, autonomous driving and safety features are out of the project scope because they are characterized by completely different sets of requirements. The main challenge here is represented by the high speed that is foreseen to reach up to 500 km/h.

## H. Tactile internet, remote surgery

The advent of improved tele-control techniques and assisted manipulation of objects, have benefited several industries from the possibility to perform manipulations in remote and secure places instead of in-situ. Ultra reliable connectivity in ultra-low latency (very few ms irrespective of the channel conditions) for extreme real time communication can be foreseen in applications such as remote driving or flying of unmanned vehicles, robotic control, remote health, remote augmented reality etc. This gives rise to several interesting yet highly challenging use cases, among which "Tactile internet" and "remote surgery" are perhaps the most representative ones. It is important to aim for near error-free transmission with a maximum packet loss rate below 0.01%. There is no way to actually fulfill these requirements and KPIs with current state of the art technologies. Fundamental changes to RATs and associated numerology are required, as well as a significant simplification of the network architecture to reduce latency to the minimum. Regarding the propagation environment, indoor and outdoor media has to be considered, as a maximum distance between transmitter and receiver should not be greater than 100 m; so as not to compromise latency; therefore deployments would likely be indoors.

# 4. mmMAGIC Technological Challenges

The use of high frequency bands, including mmWave, brings new technological challenges in different focus areas of the mmMAGIC project. In the following sections, these challenges are briefly explained from different aspects, namely: channel modeling, architecture and integration, radio interface design, and multi-antenna.

## A. Channel modeling

Over the last decade, there has been a substantial investment in channel measurement campaigns for cellular access communications in the frequency bands below 6 GHz. It yielded a number of reference channel models including 3GPP-SCM [16], WINNER [17] and COST 2100 [18]. However, at frequencies above 6 GHz, propagation characteristics and antenna designs change markedly. There is still a considerable knowledge gap due to the challenging nature of making channel measurements in the mmWave band over longer distances, and then deriving the required information for a suitable 3D channel model for mobile access environments.

A key ambition of mmMAGIC is to close this gap and develop advanced channel models that are valid above 6 GHz and go beyond existing models. The main targets for such enhanced models are to support frequency agility, accommodate 3D antenna patterns and incorporate time-varying parameters associated with access environments; such as blockages. To achieve this, six mmMAGIC partners will pool their capabilities and conduct around twenty measurement campaigns using different types of channel sounder, in frequency bands across the 6–100 GHz spectrum with up to 4 GHz bandwidth. The campaigns will include multi-frequency measurements in the same environment and study time and polarization dependent effects. The chosen propagation scenarios are: street canyon, outdoor to indoor, open square (plaza), office, shopping mall, airport, stadium and subway. The measurements will be accompanied by map-based simulations using ray tracing and point-cloud models. This hybrid approach is expected to reveal additional information about the channel, while relying on a solid basis of measurements.

## B. Architecture and Integration

A smooth integration of mmWave technologies in 5G networks brings about a range of challenges and requires changes to existing mobile network architectures, or even the introduction of entirely new architectures. In this project we consider three possible deployment scenarios for mmWave technologies: mmWave non-standalone operation (supported by lower frequency technologies), mmWave standalone operation, and mmWave as an enabler for other technologies. For efficient and seamless integration, each scenario implies a set of general challenges for the physical, medium access layer (MAC) and network layers; as well as other complex issues which depend on the specific scenario.

An efficient joint use of mmWave and lower frequency technologies requires a careful design of how to split network functionalities over the different radio technologies; for example by moving control traffic primarily to the lower frequencies (which provide better coverage), whilst keeping data traffic at mmWave frequencies as much as possible. Low frequency technologies could be used to cover mmWave coverage gaps and provide support for smoother handover to enable seamless service to the mobile users. Non-standalone operations are also faced with the important issues of optimum spacing and arrangement of multiple mmWave base stations in the operating region of low frequency cells. Furthermore, the exchange of information between the low frequency and mmWave frequency nodes, and the prospect to harmonize with low frequency technology network layers are two issues that need to be addressed.

Standalone operation will be considered as an additional RAT integrated with other legacy RATs or 5G systems. This may lead to deployment and coordination issues. The base stations will have to be optimized to provide good coverage and deal with mobility issue due to the mmWave propagation characteristics. The smaller cell sizes and the highly directional antenna beams increase the occurrence of handovers. Hence, base station coordination and terminal multi-connectivity may be required.

For enabling other technologies, mmWave technologies may be used to provide high capacity back/fronthaul links as well as access link. While the different links may or may not operate on the same frequency bands; challenges in terms of reliability, capacity, latency and connection dynamics will always surface. For example: self-backhauling at mmWave frequencies requires an efficient resource allocation mechanism to allocate the frequency resources to the backhaul and access links.

### C. Radio Interface Design

The use of mmWave technologies imposes specific challenges to the radio interface (RI), compared to sub-6 GHz frequencies. First, link budget constraints resulting from smaller antenna aperture in free space at higher RF frequencies lead to the need for multiple-antenna transmitters and/or receivers, and the corresponding directional transmission. Directional transmission can change the effective channel characteristics and other system characteristics, e.g. interference characteristics leading to different requirements and design principles of RI development. Second, as observed in recent measurement campaigns [19][20], the number of path clusters as well as the angular spread of each cluster can be small. Moreover, reflection becomes dominant while refraction and diffraction become much weaker. When users are moving, mmWave links suffer from blocking/shadowing as well as strong Doppler. Such different channel characteristics pose new challenges but also provide new opportunities for RI design, e.g. waveforms, frame structure, retransmission schemes etc.

In addition to channel aspects, critical Radio Frequency (RF)/hardware impairments that increase with carrier frequency must be taken into account; such as phase noise, the in-phase and quadrature phase (I/Q) imbalance, sampling jitter, sampling frequency offset, carrier frequency offset, Power Amplifier (PA) nonlinearity etc. Such impairments can lead to increased Error Vector Magnitude (EVM) and reduced spectral efficiency. Due to lower efficiency of PA's at mmWave frequencies, further constraint is put on the link budget.
Moreover, the expected use of wider bandwidths leads to high processing requirements, e.g. for channel decoding, increasing both hardware costs and energy consumption.

A further challenge is the use of hybrid transceiver architectures (with both analog and digital processing) to save hardware cost and power consumption. Such architecture would have an impact on RF impairment modelling as well as on specific aspects of the RI, e.g. the initial access schemes. In addition, asymmetric antenna and RF configurations in uplink (UL) and downlink (DL) also affect RI design, e.g. by considering that UL coverage will be constrained by the much lower transmitter power and beamforming gains expected at the user equipment (UE).

Lastly, the RI should support both standalone and non-standalone deployments, leading to challenges in initial access and control signaling. Accordingly, self-backhauling capabilities (where the same RI is used for both access and backhaul/fronthaul operation) may have to be considered in ultra-dense networks. Finally, uncertainty in the finally released frequency bands may demand different approaches for the above described challenges, thereby making RI design even more challenging.

### D. Multi-Antenna Challenges

Multiple-antennas at both transmitter and receiver side will be crucial to meet the performance targets of mmMAGIC test cases. mmMAGIC will perform a holistic investigation of various multi-antenna solutions from a UE and infrastructure perspective for access, backhaul and fronthaul communications in different deployment scenarios and use cases. To this end, mmMAGIC will develop very large antenna array multi-antenna transceiver technologies that can support the envisioned mmMAGIC system architecture and RI concepts at mmWave carrier frequencies.

Innovative multi-node and multi-antenna transceiver components, including RF antennas, will be investigated and developed. Beamforming at both transmitter and receiver side will form a fundamental framework for the multi-node and multi-antenna transceiver design. To this end, we will investigate adaptive beam steering, adaptive beam tracking, spatial multiplexing, transceivers robust against hardware imperfections, channel state information (CSI) and interference acquisition and cooperative/coordinated transceivers.

The objective is to achieve enhanced coverage that can mitigate severe signal blockage and coverage holes, an edgeless user experience and seamless mobility. Thus, all schemes will be designed to take into account mobility and diverse propagation conditions, building on the channel measurements and modelling work in terms of channel characteristics (e.g., Doppler spread) in the presence of highly directive transmission/reception. Key characteristics of the radio interface design, such as waveforms, will also be an important input to the design.

mmMAGIC will derive novel processing power consumption models and hardware impairment models for transceiver architectures that enable flexible evaluations of the power consumption with different configurations, e.g bandwidth, carrier frequency, antennas etc. We will also develop new channel quality indicators (CQI) and interference acquisition schemes, as well as link-to-system abstraction models for the developed transceivers.
Thus, mmMAGIC will bring actual very large mmWave transceiver scheme designs to a new and more realistic level than previous works in this field.

## 5. Conclusion

The mmMAGIC project will design and pre-develop a new system for 5G operating in mmWave bands, which will constitute a key part of the future 5G multi-RAT architecture. Several use cases have already been identified within this context, setting challenging requirements on the design of the mmWave 5G system. To achieve the different goals regarding capacity, data rates, latency; and to meet customer expectations operating in mmWave frequency bands is a really interesting opportunity to benefit from wide bandwidth and can enable very efficient capacity delivery, even in densely populated areas. mmMAGIC will specify a 5G system in the mm-wave range, tackling all the challenges related to the use of higher bands, with the ambition to take a leading role in 5G pre-standardization activities.

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